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Journal
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Volume 19 AUGUST, 1929 Number 2

THE PURKINJE PHENOMENON: QUANTITATIVELY CONSIDERED*

By W. T. M. Forbes

The relative sensitivity of the eye to light of different wave lengths varies with the brightness of the stimulus and especially with the state of adaptation of the eye (Purkinje phenomenon). If we assume that the sensitivity of the eye is primarily due to the presence of photosensitive pigments (visual purple and corresponding photopic substances) the curve of sensitivity of the eye should correspond to the sum of the curves of activity of these substances. It is assumed *a*, that the band of activity of each substance is of simple form to be represented by a probability curve (activity $= e^{-k(\lambda-c)^2}$); *b* that the band for each substance is unchanged with state of adaptation of the eye, but that the relative proportions of the active pigments is changed.

It is found that the whole range of change of sensitivity of the eye with changing adaptation can be represented as the sum of three such processes (with doubtful indication of a fourth). Two or three are photopic (called P_1, P_2 and perhaps P_3) and one scotopic S. The coefficients of the corresponding probability equations are

	c	k
P_1	605mμ	.00056
P_2	548	.00042
P_3	450 ?	.00042 ?
S	503	.00042

The values of c (the center of the absorption bands) are fairly definitely fixed by the data, those of k, representing the width of the bands

* Abstract of a paper appearing in full in The American Journal of Psychology for October, 1929.

of activity, are more uncertain, and König's and Sloan's data seem to indicate much narrower bands of activity than other data (none of it based on any substantial range of brightness).

For König's data (outer parafoveal region?) the proportions of the process for full day-adaptation are P_1 .33, P_2 .57, P_3 not over .04, S .11. For Sloan's data representing a smaller inner parafoveal area, P_1 is .2 and P_2 .8 with no definite evidence of P_3 or S. At full dark adaptation all observers get the S curve alone. For laboratory intensities (say 20 to 50 photons) König with a large field gets up to 25% of the scotopic process, modern observers with smaller fields none above about 5 photons.

A protanope observer (König data) lacks P_1; a deuteranope has both P_1 and P_2 of nearly normal value.

The fovea cannot be brought into this scheme, but its sensitivity can be almost exactly matched at high brightnesses by the curve P_2 alone, moved about 10mμ to the longer waves. P_1 appears at low brightnesses, but S is negligibly small at all brightnesses at which the fovea is sensitive. (It may be absent, as no data have been published on absolutely pure foveal stimuli.) Ives' results with the flicker photometer correspond to Sloan's with the fovea, while his results by equality of brightness represent the parafoveal phenomena as reported by other observers.

CORNELL UNIVERSITY,
ITHACA, N. Y.

INSTRUMENT SECTION

THE ANNUAL MEETING OF THE SCIENTIFIC APPARATUS MAKERS OF AMERICA

By F. K. Richtmyer*

THE SCIENTIFIC APPARATUS MAKERS OF AMERICA held their annual meeting in Atlantic City May, 16, 17 and 18, 1929. This Association, organized in 1919, includes in its membership over fifty of the leading apparatus and instrument making firms in America. Among the objects of this Association, as stated in its By-laws, are the following.

"To acquaint the manufacturers of scientific apparatus with one another in order to bring about friendly cooperation in the solution of their problems, the development of sound business ethics and high standards.

"To establish standards of weight, performance, etc.

"To encourage research among the members and in cooperation with other organizations, and to encourage the dissemination of information resulting from such researches.

"To encourage the publication of journals, books and other publications dealing with the scientific apparatus industry."

Membership in the Association is open to "any bona fide American manufacturer of scientific apparatus used in educational, industrial, scientific or research work."

In addition to discussions on the standardization of designs and terms as well as the elimination of antiquated designs—in the interest of effecting economy of manufacture and consequent reduction in price—the recent meeting was addressed by the following:

Dr. Lyman J. Briggs, Assistant Director of the Bureau of Standards, on "Testing at the National Bureau of Standards."

Dr. J. McKeen Cattell, Editor of SCIENCE, on "Reminiscences of Scientists and Scientific Publications."

Dr. Harrison E. Howe, Editor of INDUSTRIAL AND ENGINEERING CHEMISTRY, on "The Value of the Scientific Instrument Industry to the Life of the Country."

Mr. H. C. Dunn of the Department of Commerce, on "Distribution—Costs, Customers and Profits."

The following officers were elected for the ensuing terms. President: Dr. H. N. Ott, of the Spencer Lens Company, Buffalo, N. Y. Vice-President: Mr. C. Amend, of the Eimer & Amend Company, New

* This account is written on the basis of information furnished, on request of the Editors, by the Secretary of the Association.

York City. Mr. J. M. Roberts of the Central Scientific Company, Chicago, remains Secretary-Treasurer.

Among the various important activities of the Association, is the work of the various standing committees. From a booklet recently issued by this Association one finds the following items which are indicative of the type of activities undertaken by the Association during the past ten years.

1. The Association has a committee cooperating with the Bureau of Standards to facilitate the certifying of instruments and also to secure adequate appropriations for this work by the Bureau from Congress.

2. The Publication Committee of the Association is working with the Optical Society of America on the publication of "The Journal of the Optical Society of America and Review of Scientific Instruments," in which there is a section devoted to non-optical instruments.

3. The Association awards each year a prize of $250.00 for the best article appearing in the Journal of the Optical Society of America and Review of Scientific Instruments, on a non-optical instrument.

4. The Standardization Committee of the Chemical Section has considered some 3,200 items and eliminated about 2000, and a report on the retained items has been published. The Committee has also considered specifications on 114 items working in conjunction with the Medical Supply Depot of the Army.

5. The Industrial Instrument Section has a Standardization Committee working on the subject of standard definitions for pyrometric terms in conjunction with the Bureau of Standards.

In further reference to item No. 3 above—the award of a prize of $250.00 for the best article on non-optical instruments appearing in the Journal of the Optical Society of America and Review of Scientific Instruments, it may be of interest to give a list of those who have won this prize during the past four years.

	NAME	TITLE OF PAPER
1925	Loyd A. Jones	New Method of Photographic Spectrophotometry
1926	Horatio B. Williams	The Einthoven String Galvanometer
1927	E. L. Harrington	A New Type of Aspirator of High Efficiency
1928	N. E. Bonn	An Improved Rosa Curve Tracer

CORNELL UNIVERSITY,
ITHACA, NEW YORK.

A CINEMATOGRAPHIC RECORDING GALVANOMETER

By S. Bayne-Jones and L. V. Foster*

In the course of an investigation of the heat produced by growing bacteria, it was necessary to make periodic readings of galvanometer deflections due to thermocouples used to measure the changes in temperature in the cultures. The experiments required a record of the galvanometer deflection in scale divisions at intervals of 10 minutes during long periods, from 8 hours to 48 hours or longer. As visual observation of the galvanometer deflections at these intervals during many hours was both fatiguing and time consuming, it became necessary to devise a means of obtaining a photographic record of the scale division reflected from the mirror of the galvanometer together with a simultaneous photograph of a watch-face to show the time when the photograph was taken. As is well known, drums carrying bromide paper revolving at a definite rate have been used for this purpose. It seemed, however, that a more compact record, including photographs of both the scale divisions and a watch showing the time could be obtained by fitting a motion picture camera with suitable lenses and attaching this to a driving mechanism which would take pictures at more or less regular intervals. The apparatus which has been constructed for the purpose of obtaining a cinematographic record of galvanometer deflections with a time record on the same film will be described in this paper.

The motion picture camera selected was a "Sept" camera, which uses regular 35 mm film. The ordinary magazine for this camera holds a roll of film 5 meters long, providing approximately 250 frames. The shutter and film shifting mechanisms of this camera are moved by a spring and are controlled by settings of the escapement which allow the making of instantaneous exposures of 1/35 second, consecutive motion picture exposures or time exposures. An up-and-down movement of a bar opens and closes the shutter and shifts the film. This time exposure mechanism made this camera most adaptable to our purpose, because exposures longer than 1/35 second were required and because the vertical movement of the shutter and film release simplified the driving mechanism.

* From the Department of Bacteriology, School of Medicine and Dentistry, University of Rochester and the Bausch and Lomb Optical Company, Rochester, New York.

The problem was to modify the camera in such a way as to get a picture of the galvanometer reading and a watch-face in each frame. The regular lens of the camera was removed and in its place was put on one side of the center of the aperture a lens of focal length about 70 mm in front of which was located the telescope normally used to view the galvanometer scale. On the other side of the aperture was put a 32 mm focus lens and a 45° silvered prism.

The diagram (Fig. 1) shows the position and functions of the various optical elements. The regular galvanometer scale is shown at (1) and the galvanometer mirror at (2) while the telescope is shown at (3). The telescope is focused on the scale (1) with the unaided eye. The lens (4) placed back of the telescope replaces the eye and forms an image of the galvanometer scale on the film at (9). The prism (6) re-

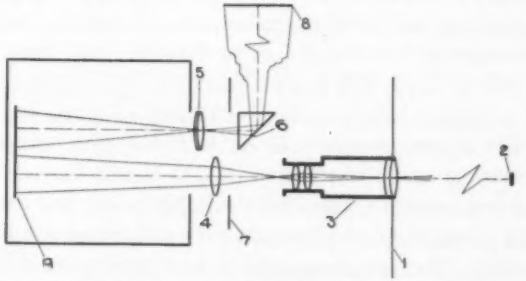

FIG. 1. *Diagram of optical parts. 1. Galvanometer scale. 2. Galvanometer mirror, 50 cm distant from the scale. 3. Telescope. 4. Lens to form image of scale through telescope on film. 5. Lens to focus watch-dial on film. Prism reflecting watch-dial at right angle. 7. Frame of external shutter and lens holder. 8. Watch dial. 9. Film.*

flects the image of the watch dial (8) to the lens (5) which in turn focuses it on the film at (9) beside the image of the galvanometer scale.

These lenses were mounted on the frame of a Bausch and Lomb "Automat" shutter. The advantage of this shutter is that a downward pressure upon the shutter release opens and closes the shutter automatically giving the required exposure. No additional setting is required to prepare the shutter for the subsequent exposure.

The entire galvanometer scale is illuminated by 10 6–8 volt 32 cp automobile lamps in series with 7 similar lamps, on a 110 V ac line. The telescope covers a field of about 30 mm on the scale so that a circular field of 10 mm diameter on the film covers 30 mm of the galvanometer scale and readings can be estimated to 0.2 mm. The field of the watch-face has to be limited at the watch by illuminating only its

face and surrounding the watch by a black background. If this black background were not used, the surrounding area would overlap on the scale and render the readings quite useless. The watch-face was illuminated with the Bausch and Lomb Wide Field Lamp No. 1813, using one of the 6–8 volts 32 cp lamps in series with the other lamps referred to above. Photographs of the face of the watch were taken through the circular opening in the ellipsoidal reflector of this lamp.

The driving mechanism is a 1/20 hp 110 V ac motor having a speed of 1725 rpm. In the use made of it here the speed of the terminal shaft is reduced by two worms and gears to 1 revolution in approximately 10 minutes, a reduction of 1:17250. As the time record is given by the photograph of the watch-face, it is not necessary to have a synchronous

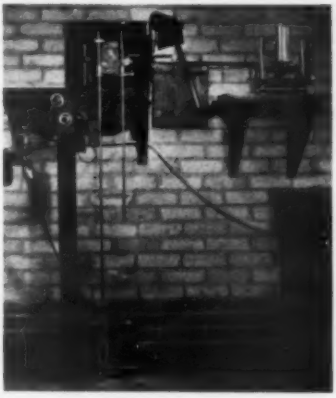

FIG. 2. *Photograph of the complete set-up.*

motor or constant speed in this driving mechanism. A vertical rod, bearing arms for pressure upon the shutter releases of the camera is attached in an eccentric manner to a disc at the end of the terminal gear on the motor shaft. This gives a slow up-and-down motion of the rod. When the rod descends, the shutter releases and film shifting mechanisms are depressed until their springs open the shutters. The external shutter automatically gives the exposure required (from 1 sec. to 1/100 sec. according to the setting). Meanwhile, the internal rotating shutter of the "Sept" camera has remained open, as governed by the time exposure setting on the camera. When the rod ascends, the external shutter release comes back into its original position, the internal

shutter snaps to the closed position by the action of its spring, and the film is shifted by spring action to a new frame, ready for the next exposure. A simple sliding switch is attached to this vertical rod, so adjusted that the lights are turned on shortly before the shutters open and are turned off after the shutters are closed.

FIG. 3. *Photograph of camera, shutter releases, watch and galvanometer. See Fig. 4 for details.*

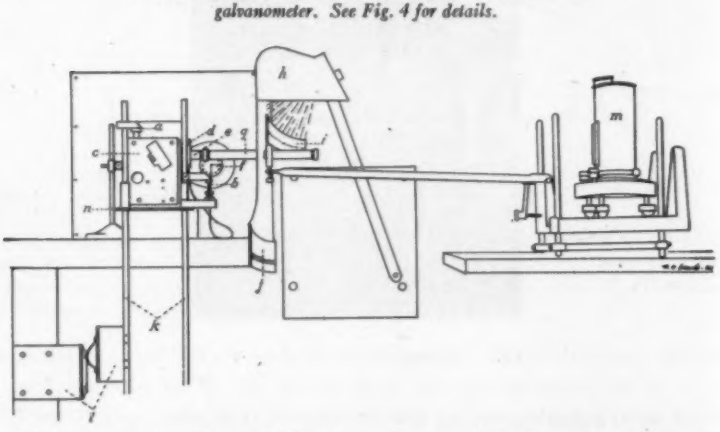

FIG. 4. *Drawing from photograph (Fig. 3). a. Shutter and film release of "Sept" camera in contact with arm of driving shaft. b. Shutter release of external automatic shutter, in contact with anterior arm of driving shaft. c. "Sept" camera. d. External automatic shutter. e. Prism over lens for focusing watch-dial on film. f. Watch-dial as seen through circular opening in back of ellipsoidal reflector. g. Telescope. h. Reflector for row of 10 6–8 volt 32 cp lamps to illuminate galvanometer scale. i. Galvanometer scale. j. Additional scale for "pilot" spot light to give visual observation of galvanometer deflections when needed. k. Vertical shafts of driving mechanisms carrying arms to produce downward pressure on shutter releases. The lateral arms a and b are adjusted to open the internal shutter first. l. Sliding switch for lamps. m. Galvanometer.*

The assembled driving mechanism, camera, watch, scale, telescope and galvanometer and lamps are shown in Figs. 2, 3, and 4. Fig. 5 re-

produces 4 frames from an actual record of the rise of temperature in a flask containing junctions of the thermocouple attached to the

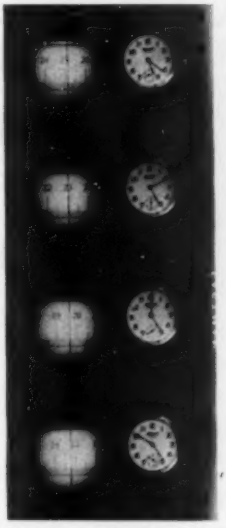

FIG. 5. *Print from film giving part of an actual record.*

galvanometer. This shows the galvanometer deflections in scale divisions at the times indicated by the watch-dial.

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ROCHESTER, N. Y.

BAUSCH AND LOMB OPTICAL CO.,
ROCHESTER, N. Y.

A PRESSURE CONTROLLED McLEOD GAUGE

By Newton Underwood

If the vacuum goes bad or is not controlled properly on either side of a vacuum controlled McLeod guage, disastrous results follow. In order to avoid this difficulty a gauge was made in which the mercury was controlled by the converse method. It was found that an atomizer bulb with good valves (one with rubber valves is satisfactory) would produce a pressure of 50 or 55 cm of mercury. Usually a McLeod gauge can be made so that the necessary motion of the mercury is well within this limit.

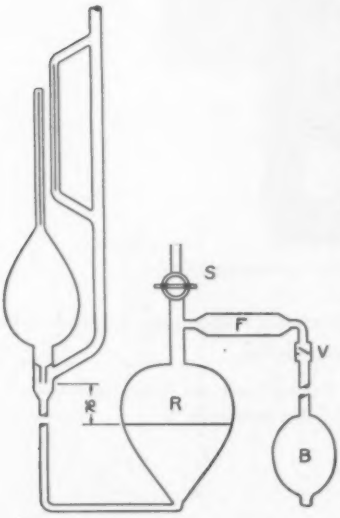


Fig. 1. *McLeod guage.*

In the arrangement here shown the usual glass tube coming from the gauge proper goes to a mercury reservoir *R* which is at such a level that when the gauge is evacuated, the mercury column comes to rest at a point just below the side tube. With the stopcock *S* closed the atomizer bulb *B* will furnish sufficient pressure to move the mercury to any desired height in the gauge. Opening the stopcock *S* relieves the pressure, and the mercury comes back to its normal position. *F* is an air filter to prevent contamination of the mercury. The valve *V* should hold fairly well. It was found that an automobile tire valve with its spring weakened (by heating), and its seat greased with stopcock grease, would work.

This method of moving the mercury can, of course, be applied to mercury shut-offs, etc. in which case the valve *V* had best be replaced by a stopcock. It seems to have a slight advantage over the method described by Dr. Donald L. Hay[1] in that there are no moving parts, the over-all height of the gauge is less, and it possesses the same advantage of cleanliness.

Brown University,
Providence, Rhode Island.

[1] J.O.S.A. & R.S.I., 7, p. 1015; 1923.

A VOLTAGE REGULATOR FOR GAS DISCHARGE X-RAY TUBES

By F. E. Haworth

This note describes a device used in connection with a gas discharge x-ray tube, to regulate the voltage across it by automatically adjusting a mercury valve between the tube and the pumps, thus controlling the pressure of the gas. It has been used with tubes of the Hadding[1] and Shearer[2] types and has operated satisfactorily for more than a year. It was designed to replace the regulator described by Bozorth,[3] which is similar in principle but has certain disadvantages, for example the moving parts have high inertia and adjustment is required when the atmospheric pressure changes.

In the present design, shown in Fig. 1, the armature was placed inside the vacuum system, and supported by an aluminum cylinder floating in mercury. This cylinder and the armature are then the only moving parts, and have a comparatively small inertia.

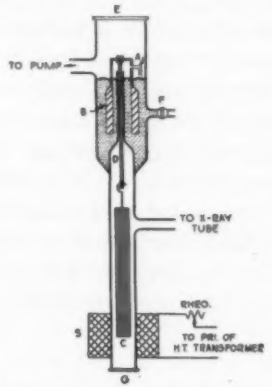


Fig. 1. *Diagram of the regulator.*

The gas pumped from the x-ray tube must pass through the little elbow *A*, and through the small space between it and the mercury surface. It is the automatic adjustment of this small space which regulates the gas pressure in the x-ray tube. The rod *D*, which supports

[1] Zs. f. Physik, *3*, pp. 369–71; 1920.

[2] Bragg and Bragg "X-rays and Crystal Structure," 5th ed., G. Bell & Sons, London, pp. 34 & 295; 1925.

[3] Jour. Am. Chem. Soc., *49*, p. 971; 1927.

the armature *C*, is rigidly fastened to the aluminum cylinder *B*, which floats in mercury, and which is preferably turned from one piece of aluminum. Its size is such that the weight of the armature plus the pull of the solenoid *S*, at an average useful voltage, will submerge the float to the elbow *A*. The stop-cock *F* is provided so that the mercury level may be easily changed. *E* is a metal disc sealed on with wax, and allows the float to be removed when necessary. The disc *G* serves the same purpose for the armature. The elbow *A* may be sealed into the float with hard wax, and the juncture of the rod *D* and the float should also be sealed in the same way.

The operation is as follows: As the x-ray tube is exhausted the voltage across it increases and with this the voltage of the primary of the high tension transformer. This causes the solenoid *S* to pull on the armature *C*, submerging the float until *A* dips under the mercury surface, cutting off the pump. The evolution of gas in the x-ray tube then increases the pressure until *A* is lifted from the mercury. If the end of *A* which dips under the mercury is given a slanting cut, it will be lowered to such a point that just enough gas will be pumped out to compensate for that produced in the tube, which will thereby be kept at constant voltage. If no gas is produced in the x-ray tube a small leak will have to be introduced. A rubber tube connected to the fore-vacuum and partially closed by a pinch-cock was found to be the most convenient. The regulator can be adjusted for any desired voltage by the rheostat *Rh*, or by moving the solenoid up or down.

Air must be let into the system with caution, especially if it is let in on the pump side, as the elbow *A* may be forced under the mercury by a sudden increase of pressure, and the mercury forced over the top of the interconnecting tube and into the lower part of the regulator.

BELL TELEPHONE LABORATORIES,
NEW YORK CITY.

THE CAESIUM-MAGNESIUM PHOTOCELL

By V. Zworykin and E. D. Wilson

ABSTRACT

The values of the work functions of the alkali metals and their color-sensitivity curves indicate definitely that caesium is the most favorable material for use in photocells.

The practical difficulties of handling caesium metal have been overcome in the caesium-magnesium cell, in which a freshly evaporated coating of magnesium not only binds an invisible layer of caesium to the walls of the cell, but also provides an electrical connection with the cathode terminal.

Average color-sensitivity curves are given for more than twenty cells. They show that the maximum sensitivity lies at about 4850A, as compared with 4400A for pure potassium, 5390A for pure caesium, and 5560A for the human eye.

The photoelectric properties of the cell are detailed by means of response-voltage curves, response-illumination curves and illumination limit curves. The maximum response for vacuum type cells is about 2 microamperes per lumen, and for gas-filled cells about 25 microamperes per lumen under normal operating conditions.

Several commercial applications are described. Further development work is now in progress.

INTRODUCTION

The type of photocell described in this paper was developed several years ago. Since that time further progress has been made and still better results have been obtained. It was thought, however, that it would be of interest to give an account of the earlier work since it represented an independent method for preparing photocells.

Since the time of Elster and Geitel,[1] to whom perhaps should be given the credit for constructing the first successful photocell about 30 years ago, only slight modifications had been made in their methods by subsequent workers until quite recently. Usually the method consisted of distillation in vacuum of one of the alkali metals—chiefly potassium—onto the walls of a glass bulb which, in some cases, had been previously coated with a metallic film. The potassium would then be treated by an electric discharge in hydrogen in order to increase the sensitivity by converting the surface layer supposedly into its hydride. An inert gas, such as argon, had to be introduced to preserve the sensitivity and at the same time to increase the output by means of ionization.

During the last few years, when photocells became more and more important factors in numerous commercial applications, considerable work has been done to improve the quality of photocells, particularly

[1] Elster and Geitel. For a description of their potassium hydride cell, see Phys. Zeit., *11*, p. 257; 1910.

with respect to increase of sensitivity and stability and to decrease of dependence on variations of temperature.

Such improvements have been made for example by J. Kunz and Stebbins,[2] who improved Elster and Geitel's technique; by Ives,[3] who worked with thin films of rubidium; by Burt,[4] who deposited sodium electrolytically through glass; by Zworykin,[5] who similarly deposited potassium by electrolysis through potassium glass; and by Case,[6] who produced the barium cell. And yet better cells were demanded.

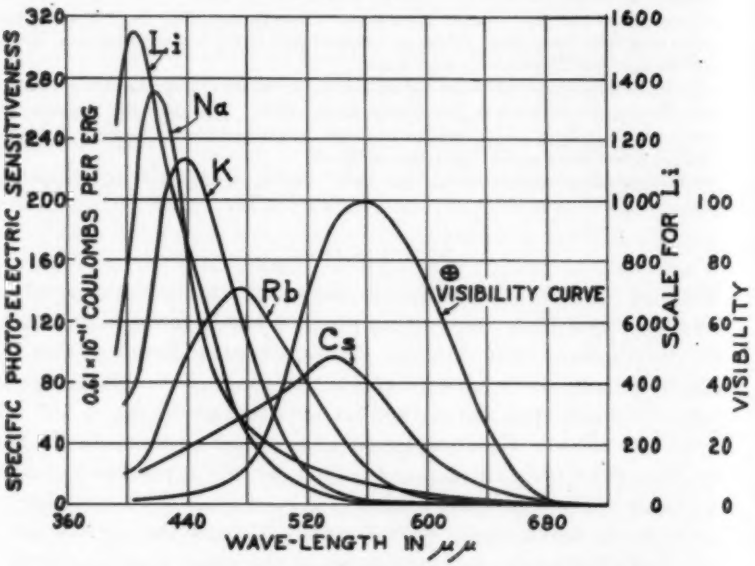


FIG. 1. *Color-sensitivity curves for photoelectric cells of the alkali metals compared with visibility curve for human eye.*

DEVELOPMENT OF CAESIUM-MAGNESIUM PHOTOCELL

If we survey the whole group of alkali metals with respect to their work functions, we find that the values decrease regularly as the atomic weight increases, —thus for Li, 2.35 volts; Na, 1.82; K, 1.55; Rb, 1.45; Cs, 1.36. As should be expected, the wave length of maxium photoelectric response for these metals shifts toward the red in accordance

[2] J. Kunz and Stebbins, Phys. Rev., 7, p. 62; 1916.
[3] Ives, Astrophys. Jour., *60*, p. 209; 1924.
[4] Burt, J.O.S.A. & R.S.I., *11*, p. 87; 1925.
[5] Zworykin, Phys. Rev., *27*, p. 813 (A); 1926.
[6] Case, Am. Electrochem. Soc., Trans., *39*, p. 423; 1921.

with their advancing position in the periodic table. Careful measurements by Miss Seiler,[7] show that the wave length of maximum response for Li is 4050A; Na, 4190A; K, 4400A; Rb, 4730A; Cs, 5390A. Her color-sensitivity curves are shown in Fig. 1. There are also second maxima in the ultraviolet, but those are not of interest for our present discussion.

Since the energy distribution curve for ordinary incandescent sources (see Fig. 2) has its maximum in the deep red, it is apparent that caesium is the most suitable metal to be employed in photocells.

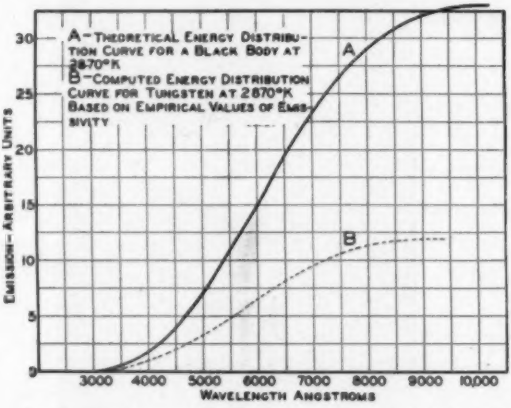


FIG. 2. *Wien's energy distribution curve for a black body and corrected curve for tungsten.*

However, the difficulty to be met in using this metal is considerable. Its melting point is only 26.5°C, and it is therefore a liquid at about room temperatures, and in vacuum it is so volatile that it quickly redistills and coats all insulating surfaces. The remarkable work done by Langmuir and Kingdon[8] shows that under certain conditions caesium can be made to cling to a metallic surface even at temperatures considerably above the melting point of the caesium. An exactly similar method was attempted for photocells, but was found to be impractical.

An independent method was developed for binding the volatile caesium, which proved subsequently to be admirably suitable for commercial cells. It was discovered that freshly distilled magnesium has the property of retaining caesium on its surface without altering appreciably

[7] Miss Seiler, Astrophys. Jour., *52*, p. 129; 1920.
[8] Langmuir and Kingdon, Phys. Rev., *21*, p. 380; 1923.

the photoelectric character of the alkali metal. A magnesium film was produced in the normal fashion by evaporation in vacuum, and served not only to bind the caesium but also as a metallic conductor on the surface of the glass bulb. Practically all of the accepted methods for producing pure caesium proved to be satisfactory. Certain caesium compounds such as its chloride, carbonate, trinitride, or dichromate, all of which may be decomposed thermally, gave good results.

FIG. 3. *A typical caesium-magnesium photocell.*

The appearance of a practical photocell made in this manner may be judged from Fig. 3.

COLOR-SENSITIVITY CURVES

Color-sensitivity curves were obtained in the following manner. A Mazda lamp with tungsten filament served as a source of light. The lamp was burned at a temperature of 2870°K as measured by an optical pyrometer. Radiation from this source was concentrated by a suitable optical system (see Fig. 4) upon the collimator slit of a Hilger glass prism monochromator. A narrow portion of the resultiug spectrum was admitted through a second slit into the window of the photocell, which was enclosed in a dark box. Leads from the photocell ran through

a set of high potential dry cells and a 1 megohm resistor to the terminals of a sensitive Leeds and Northrup galvanometer.

A gross response curve was obtained by plotting actual galvanometer deflections for a given fixed applied voltage against the corresponding wave lengths of radiation incident upon the photocell as measured by the calibrated drum of the monochromator. These data were reduced to

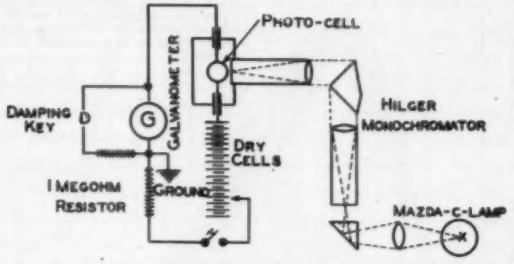


FIG. 4. *Diagram of apparatus used for taken data for color-sensitivity curves.*

response per unit wave length by correcting for effective slit width; i.e., by correcting for prismatic dispersion in the spectrum. A final reduction of data was made to response per unit energy by correcting

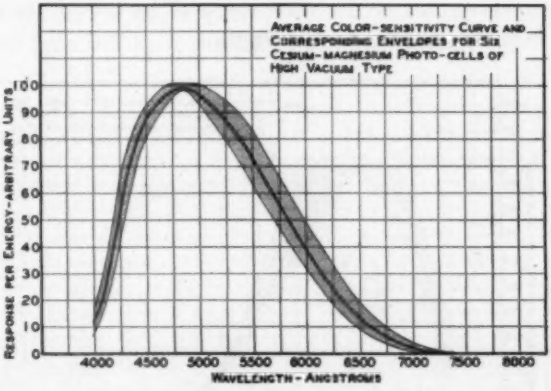


FIG. 5. *Color-sensitivity curve for vacuum cell.*

for the distribution of energy in the source. In Fig. 2, curve *A* represents the distribution of energy in the spectrum of a black body at 2870°K as computed from Wien's familiar formula. Curve *B* represents the corresponding distribution for a tungsten filament at the same temper-

[9] Forsythe and Worthing, Astrophys. Jour., *61*, p. 146; 1925.

ature as determined from curve *A* by applying the emissivity factors empirically established by Forsythe and Worthing.[9]

Fig. 5 gives the average color-sensivity curve for six caesium-magnesium cells of the vacuum type. The shaded area represents the total

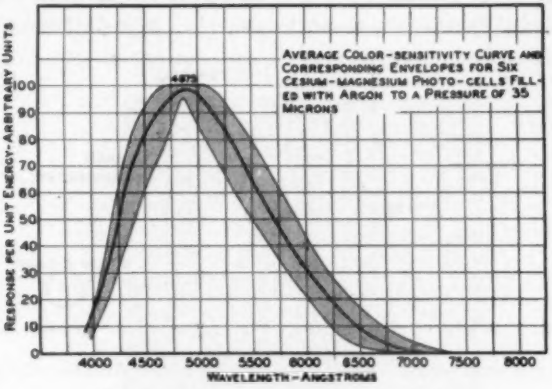


FIG. 6. *Color-sensitivity curve for argon cell.*

space covered by the six individual curves. It is worthy of note that no two cells give exactly the same shape of curve, nor do the several maxima come at the same wave length.

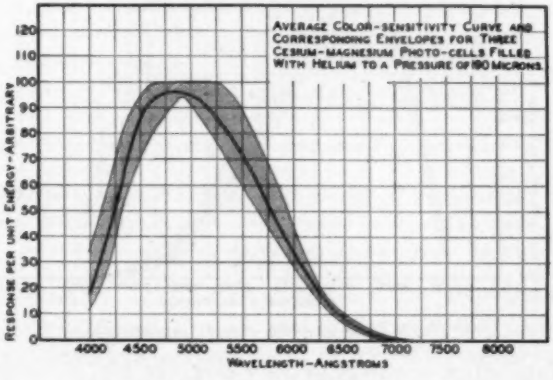


FIG. 7. *Color-sensitivity curve for neon cell.*

Figs. 6, 7, and 8 represent similar curves for cells filled to low pressures with argon, neon and helium, respectively.

It is to be observed that the maximum sensitivity for all the types

occurs near the wave length 4850A, as compared with 4400A for pure potassium, 5390A for pure caesium, and 5560A for the human eye (see Fig. 1).

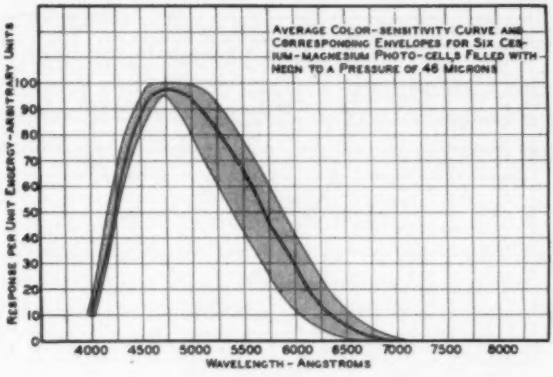


FIG. 8. *Color-sensitivity curve for helium cell.*

CHARACTERISTIC CURVES

Fig. 9 shows how the anode-cathode current in a vacuum cell at constant illumination varies with applied voltage. The current reaches a saturation value of about 2 microamperes per lumen.

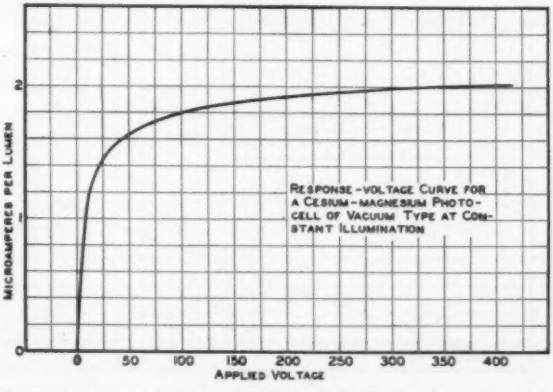


FIG. 9. *Response-voltage curve at constant illumination for vacuum cell.*

Curve *A* of Fig. 10 represents corresponding data for a gas-filled cell. At 0.10 lumen this cell can be operated safely at 180 volts, yielding a current at the rate of about 25 microampers per lumen. Curve *B* in

the same figure indicates the maximum light flux permissable at various voltages. Increase of illumination above these maximum values will cause the cell to break down into a self-sustained glow discharge.

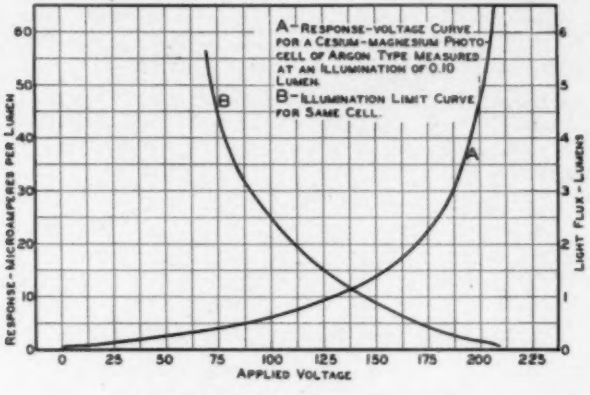


FIG. 10. *Characteristic curves for gas cell.*

The linearity of the relation between illumination and current for a given voltage is well shown in Fig. 11. Even for a gas-filled cell, the relation is strictly linear until the light flux begins to approach the

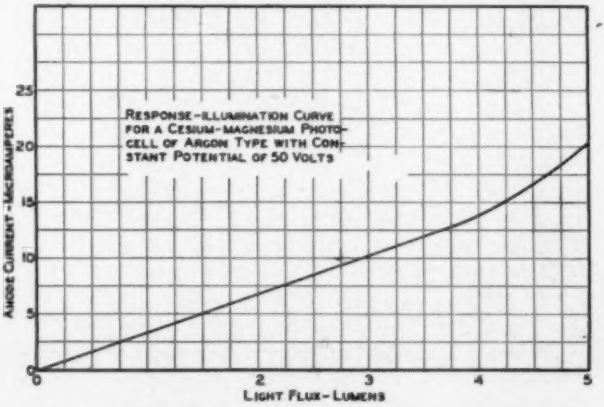


FIG. 11. *Curve showing proportionality of response current to illumination.*

illumination limit. For high-vacuum cells the linearity is valid over all ranges of illumination.

STABILITY

A commendable quality of caesium-magnesium cells of vacuum type is their indefinitely long life. Several samples selected at random from stock and operated at an intense illumination of about 350 foot candles and at nearly saturation voltage, have shown no appreciable decrease in sensitivity over a period of 10,000 hours.

The dependence of current response upon temperature is practically zero. Measurement made with cells subjected to temperatures as low as that of liquid air and as high as 150°C showed no apparent change in sensitivity.

COMMERCIAL APPLICATIONS

The caesium-magnesium cell has been put to many practical uses. In combination with either a radio tube or a Knowles glow tube, it has been made into a unit capable of operating sturdy relays in many types of circuits, as for example in traffic control. The gas-filled cell has served satisfactorily in the Photophone sound-reproducing assembly, and perhaps with most success in the picture transmission apparatus developed by one of the writers.

Large sized cells of vacuum type have been utilized in television transmission, while midget cells, combined in series, have found application in machines for sorting material.

Innumerable other applications are now being made or are in development; and with the present rate of progress, the photocell promises to become as familiar as the radio tube.

RESEARCH DEPARTMENT,
WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY,
EAST PITTSBURGH, PA.,
Jan. 24, 1929.

AN INTERFEROMETER USING PLANE-POLARIZED LIGHT

By J. W. Beams, L. G. Hoxton, and F. Allison

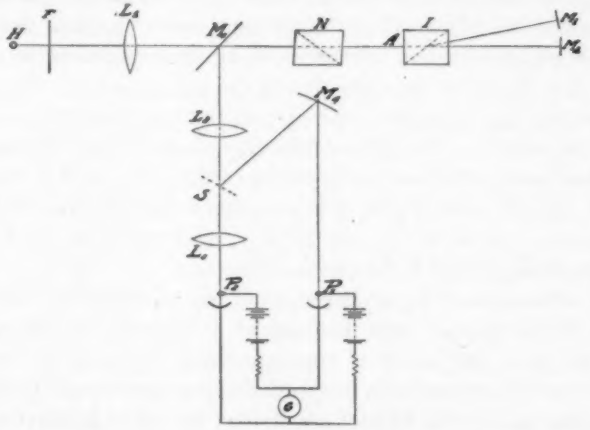
The problem in which one or both of the light beams in an interferometer must be plane-polarized, often presents itself. Many such instruments have been described and hence a considerable range of choice is possible depending upon the purpose in view. In some types, such as the half-shade interferometer described by Cotton[1] or by Skinner and Tuckerman,[2] where the determination of the variation in optical path depends upon a measure of the change in the ellipticity of polarized light rather than the usual shift of the fringes, a precision as high as one twenty thousandth wave length is claimed. To attain such high precision, the optical parts must be of a very fine quality and the experimenter must be quite skilful, especially in matching light intensities. In fact, the experimental difficulties are so great that the half-shade interferometer has not been generally used regardless of its many important possible applications. Where the precision of the instrument is considerably reduced, the experimental difficulties are of course very much lessened, but the demand for fine optical parts still remains. In many experiments, where the light need not be completely plane-polarized in both arms of the instrument, almost any ordinary interferometer as, for example, the Jamin type, can be used by merely polarizing the incident light.

We have had occasion to construct an instrument by which a change in the optical path of completely plane-polarized light could be measured with a precision of approximately one one-hundreth of a wave length. The instrument turned out to be so simply adjusted and easily operated, in addition to being nearly independent of the eye of the observer, that it was thought worth while to describe it here.

Light from a mercury arc H, passed through a filter F which transmits only a single line, was made almost parallel by the lens L_1 and plane-polarized by the Nicol prism N. The light then entered a crystal of Iceland spar (or a double image prism) which is so oriented with respect to N that two beams of equal intensity polarized in perpendicular planes emerged. Each of these beams is reflected back practically on its path by plane mirrors M_1 and M_2 and recombined at A, forming

[1] Cotton: Comptes Rendus, *152*, pp. 131–33; 1911.
[2] Skinner and Tuckerman, Phys. ZS., *12*, p. 620; 1911.

elliptically polarized light. It then continues through N and is reflected by the half silvered mirror M_3 into the lens L_2. In the position S a system of light and dark bands is formed. Then if M_1 is moved with respect to M_2 or the optical path AM_1 changed with respect to AM_2, these bands or "fringes" shift their position. The exact shape of these fringes depends somewhat upon the optical surfaces. If the optical path AM_2 differs from the optical path AM_1 by an integral multiple of one fourth of a wave length, the two beams recombine at A to form plane polarized light.



Since now the two beams are reflected not quite, but almost, back on their original paths, the theory of the ordinary interferometer is applicable. It can be shown that the ellipticity of the light is constant over certain loci of the same type as the fringe systems of the Michelson interferometer. The ellipticities in adjacent loci, however, vary by all stages from light polarized in one plane to that polarized in another perpendicular to it. Therefore, when this light passes back through N, dark bands are formed where the light is polarized in a plane perpendicular to its plane of transmission. A change in the optical path AM_2 by half a wave length, while AM_1 remains constant, shifts one dark fringe into the position of the next. If white light is to be used, a crystal of Iceland spar of proper thickness must be placed in the shorter optical path to make the two paths equal. We have, however, used only monochromatic light in our experiments, rendering the plate unnecessary.

In order to measure small shifts of these fringes, a system of slits whose dimensions were nearly identical with those of the fringes themselves, was made by scraping off the silver from a mirrored surface. It was then placed so that the center of each reflecting portion received the edge of a fringe. About half of the light, therefore, was reflected and half transmitted. The reflected light (coming off at a small angle) fell upon the concave mirror M_4 and was focused on a photoelectric cell P_1; while the transmitted portion was focused on a second similar photoelectric cell P_2 by the lens L_3. The circuits of P_1 and P_2 are arranged to send their currents through a high sensitivity galvanometer in opposite directions. If now the fringes move, the light received by one cell is increased and that received by the other is decreased. The result is a change in the deflection of the galvanometer. The relation between the galvanometer readings and the fringe shifts, provided the latter are small, can be easily obtained by placing tubes containing a gas of known index of refraction in the two arms AM_1 and AM_2 respectively and then determining the galvanometer deflections as a function of the pressure of the gas in one tube. Other methods could be used but the above proved to be quite satisfactory.

The advantage of this arrangement of two photoelectric cells instead of one lies in the fact that fluctuations of intensity in the source of light are, to a first order of approximation, compensated out. The instrument is comparatively free from troubles due to small temperature variations but, for the highest sensitivity, the whole apparatus, except the light source, should be placed in a constant temperature box with a water cell placed between the arc and the first lens. In our experiments the interferometer and slits were placed on a Julius suspension in order to avoid troublesome small vibrations.

It is of course possible to use the photoelectric cell arrangement to detect the fringe displacement in any kind of interferometer provided the fringes are comparatively sharp. The precision obtainable depends upon the distribution of light in the fringes, the strength of the light source and the sensitivity of the photoelectric cell and circuit. We could easily measure a displacement of one one-hundreth of a fringe and we believe the sensitivity can be considerably increased, if desired, by taking a few further precautions.

UNIVERSITY OF VIRGINIA.

AN ADJUSTABLE MOUNTING FOR WALL GALVANOMETERS

B. J. Smyth and L. W. Taylor

The experimenter has frequent occasion to attach to the wall instruments which subsequently require levelling. The most common of these instruments is the wall galvanometer. An adjustable wall mounting is described herewith, designed primarily for galvanometers but applicable to other instruments.

This mounting has three features. It possesses a degree of ruggedness not evident in the few wall mountings at present on the market. It possesses slow-motion adjustment about both horizontal axes. Provision is made for attaching the reading telescope to the main casting (this being screwed to the wall) instead of to the galvanometer itself.

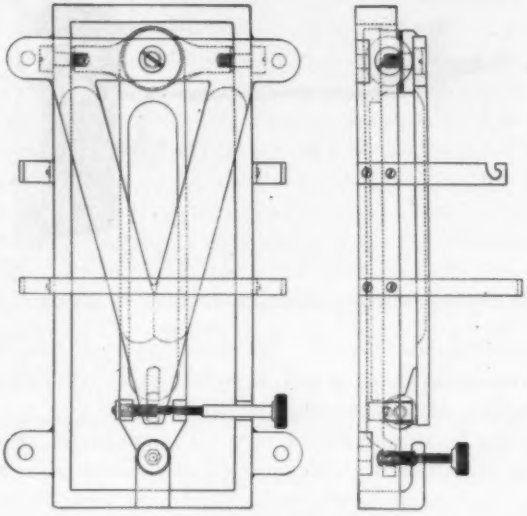


Fig. 1. *Elevations of galvanometer mounting.*

The mounting is simple. It consists of three castings, the main casting or base being attached to the wall. The galvanometer is attached to another casting. A number of holes are drilled and tapped in this casting so that most standard makes of wall galvanometers can be attached without further machine work. The third casting serves to link these two, the joints providing for the feature of adjustability.

The two rotations are effected by heavy, easily accessible slow-motion screws with large, knurled heads. All lost motion is eliminated by stiff springs.

The telescope frame is hooked to heavy brass strips which are attached to the main casting. This eliminates jarring of the galvanometer when the telescope is touched, a common source of difficulty. Different makes of galvanometer, and possibly different models of the same make, will require different forms for these brass strips. The user will prefer to adapt this part of the instrument to his own requirements. The only tools required to shape the brass strips are a drill, a vise, and a hammer. In Fig. 2 the mounting has been prepared to receive a Leeds and

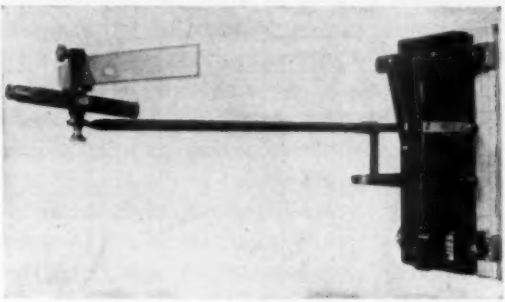


FIG. 2. *Galvanometer mounting with telescope arm attached.*

Northrup galvanometer type P. The telescope frame may be used on this mounting as shown or, at will, attached directly to this or another galvanometer by simple reversing the pins.

The castings illustrated are of iron. The magnetic effects of the iron night be objectionable under certain circumstances, in which case the castings could be made of brass or aluminum. Two dozen of these mountings have been in use in our laboratory during the current year. No observable effect of the iron has developed.

This mounting is sufficiently simple and inexpensive to obviate most of the occasions for the use of wooden wedges, cardboard packing, and other makeshifts that so commonly decorate the base of wall-mounted instruments.

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MECHANICAL AND ELECTRICAL DEMONSTRATION OF RELATIONS BETWEEN STANDING AND TRAVELING WAVES

By W. L. Everitt

The equations ordinarly used in the solution of long electrical lines, vibrating strings, or organ pipes do not give a very clear physical picture of the relations involved. It is the purpose of this article to describe a mechanical and an electrical model which portray these physical relations.

A disturbance impressed on an electrical line having distributed constants of inductance and capacitance, or a mechanical system with distributed mass and elastance, has a finite velocity of propagation. Furthermore, when the disturbance reaches the far end of the line, part of the energy in the disturbance will be reflected unless the load impedance is equal in magnitude and phase to the surge impedance of the line and therefore can receive the current and voltage in the same ratio as existed while they were being propagated along the line.

As a result of this, there will exist on the line, in the general case, two waves traveling with equal velocities in opposite directions, and being attenuated or dissipated as they pass along the line, due to losses in the line. This conception of two waves is usually more important in the electrical than the mechanical case because of the better control of terminal impedances, thereby controlling the magnitude of reflection. A wave passing in the positive direction along the x axis, can be represented by the equation:

$$y = Ae^{(-\alpha - i\beta)x}$$

while a wave traveling in the negative direction along the x axis will be represented by a similar equation:

$$y = Be^{(+\alpha + i\beta)x}$$

In these equations, the real exponent denotes a loss of a certain proportion of energy or attenuation, while the imaginary exponent shows a shift in phase along the line due to the finite velocity of propagation, making corresponding events occur at later instants as the wave progresses.

The complete solution of voltage or current on an electrical line or displacement or velocity in a mechanical or acoustic system can therefore be represented by the equation

$$\bar{y} = \bar{A}e^{-\gamma x} + \overline{B}e^{+\gamma x}$$

in which the terms $\bar{A}$, $\overline{B}$, and γ are complex functions of the constants

of the line, load, and generator. In the electrical case, it is customary to reassemble the exponential equation into one involving hyperbolic functions, to obtain the familiar transmission line equations of which the following is an example

$$E_1 = E_2 \cosh \gamma x + I_2 Z_0 \sinh \gamma x$$

While the hyperbolic functions are ordinarily considered more simple to evaluate, it is at this point that one is apt to lose sight of the physical idea of an initial and a reflected wave. In mechanical vibrations it is more customary to show similar relations by complex circular functions. The phase angle between two waves varies along the line, and therefore when the summation is performed, maxima where the two waves

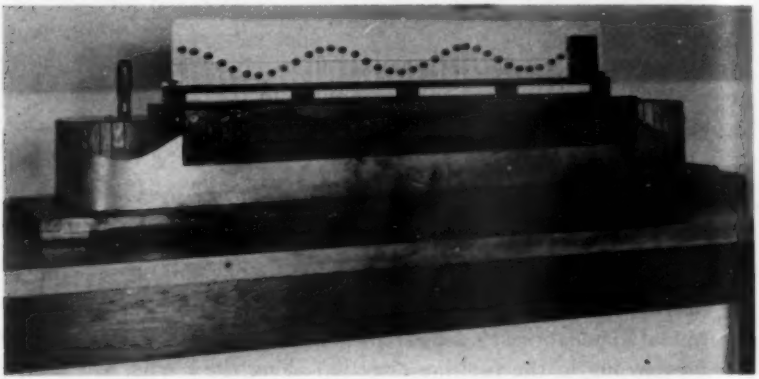


FIG. 1. *Mechanical wave model.*

are in phase and minima where the waves are 180° out of phase will be obtained. The presence of maxima and minima are generally spoken of as standing waves, and such waves can be detected on an electrical line with a voltmeter which reads effective values, or observed by the maximum motion of a string, while a simple traveling wave cannot be detected by such means.

MECHANICAL MODEL

In order to show the phase relations from point to point, and their resulting summations, the model shown in Fig. 1 was constructed. A brass band has its upper edge cut in the form of a sine wave. Ten cycles cover the total length of ten feet. This brass band was passed around two cylinders which rotate on vertical axles at the two ends of the model. At intervals of one and one-half inches are vertical slots in two horizontal grooved strips, one on the front and one on the

back part of the band. In these vertical slots rest brass rods. These rods are constrained by the slots from moving horizontally, but their vertical motion at each end is determined by the sinusoidal cut on the brass band upon which they rest. When the cylinder is rotated, the ends of the rods nearest the observer show a traveling wave moving from left to right, while the ends away from the observer show the motion of the reflected wave moving from right to left.

At the center of each rod, and pivoted to it, is attached a vertical rod. The movement of the center of the rod is always half the sum of

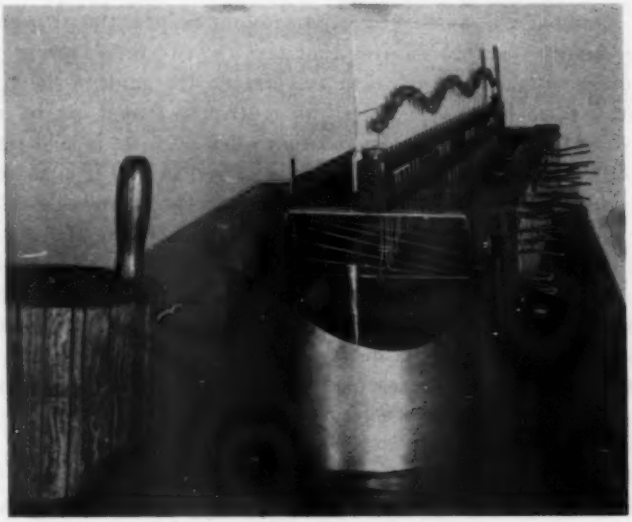


FIG. 2. *End view of mechanical wave model.*

the movements of the two ends of the rod. Since the one-half is a constant factor, the movement of the attached vertical rod therefore shows the sum at that point of the two waves. Attached to the top of these vertical rods are wooden beads. These vertical rods are constrained to move in a vertical direction only, by means of a third horizontal strip with drilled holes through which the rods pass. This construction is shown by the end view of Fig. 2, where the cylinder has been removed.

When the guide of the vertical rods is half way between the front and back of the brass band and parallel to it, the reflected wave is of the same magnitude as the initial wave, and there is no attenuation of either wave. The standing wave shown by the beads has nodal

points, with no motion, at intervals of one-half wave length. This condition is approximated in a radio antenna where the attenuation per wave length is small. A similar condition exists in the vibration of strings and organ pipes.

An examination of the motion of the rods gives a very accurate picture of the phase relations between the two waves at different points along the line, and therein lies one of its most important advantages. At the nodal points, the two ends of the rod will be out of phase, one end moving up as the other moves down, giving a rocking motion about the center, and hence imparting no motion to the bead. On the other hand, at the anti-nodal or maximum points, the two ends of the rods move together showing that here the two waves are in phase.

In order to make the model more versatile, the guide of the vertical rods rests at each end on a slotted brass strip, so that it can be moved relative to the brass band. Its position when once set is held rigid by means of thumb screws. If the guide is moved so that it is nearer the front side of the brass band, but parallel to it, the front edge will have more effect on the beads than the back, and therefore the condition where the reflected wave is weaker that the initial wave is simulated. Since the guide is parallel, there is still no attenuation. Due to the weaker reflected wave the nodal points will not have zero motion, for the motion will be finite but a minimum with respect to the other points. This condition corresponds to a termination on the line where there is some absorption of energy, and therefore the load has a resistance component.

If the guide is placed at an angle to the brass strip, the relative magnitude of the initial and reflected waves will change along the line, and therefore correspond to the case where attenuation or absorption in transmission exists. The initial wave will be reduced when passing in the positive x direction, while the reflected wave will be reduced while passing in the opposite direction. The nodal points will therefore have the least motion near the receiving end, and will gradually increase as the sending end is approached. While the attenuation cannot be made exponential by this model, the other relations are shown very well.

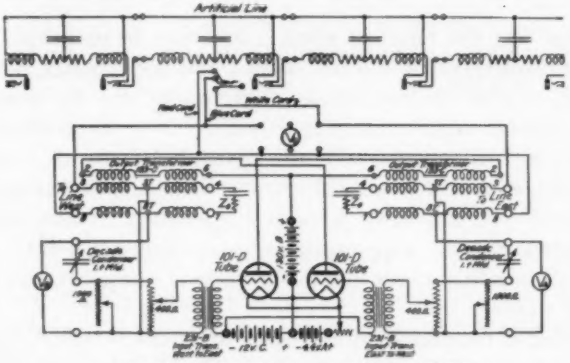
In order to show on the beads the motion when all the energy is absorbed at the receiving end and there is no reflected wave, a horizontal stop is provided on the back of the model which can lift the rods clear of the brass band on the back. A single traveling wave with or without attenuation can then be shown.

The reactive component and magnitude of the load determines the phase shift during reflection. In order to show this action it is only necessary to change the bead acting as the end of the line. This can most readily be done by covering one or more of the end beads by a small black screen provided, and shown at the right of Fig. 1.

Aside from its application to the transmission line relations, this model also is an effective way in elementary theory, of showing the need for vector addition of sine waves out of phase for a variety of phase angles between two vectors adding together are available at the different points along the line.

ELECTRICAL MODEL

To supplement the mechanical model, an electrical model was constructed in which the initial and reflected waves are separated for measurement, and compared with their sum.



22-TYPE TELEPHONE REPEATER CIRCUIT
TO SHOW ANALYSIS OF WAVES ON A TRANSMISSION LINE

FIG. 3.

The technique of separating two waves passing in opposite directions along a line was first developed for the purpose of duplex telegraphy, so that messages could be sent simultaneously in opposite directions. This technique was further refined for application to telephone repeaters, as it is necessary to separate the two waves in order that a repeater may be made to amplify in both directions without howling. The method used here is that of the telephone repeater, with some simplification, since no gain is needed.

The wiring diagram is shown in Fig. 3. The gain control is adjusted so that there is no gain or loss in passing through the apparatus. The impedances must be carefully adjusted so that there is no reflection at the repeater. The separation of the two waves is obtained by a

bridge balance, and the reader is referred to the extensive literature on telephone repeaters for further information upon the details. Voltmeter *A* will read the voltage of the initial wave traveling from the generator to the load, while Voltmeter *B* will read the voltage of the reflected wave traveling in the opposite direction. Voltmeter *C* will read the sum of the two waves, as it is attached at a point where the two waves are coexistant. The oscillator is connected to the right of the artificial line shown in Fig. 3 and the load is connected to the left. Voltmeter *C* may be connected to either side of the repeater by a switch and can be used in adjusting the gain.

It is necessary that the voltmeters should not introduce any disturbance in the line, and this together with the low voltage used dictated the use of vacuum tube voltmeters. These voltmeters have one stage of amplification with a vacuum tube detector operating a d.c. milliammeter.

In order that the relations along a line may be observed, an artificial line consisting of *T* sections is used and the repeater is attached to a plug, so that the magnitude of the waves may be measured at different points. When this plug is moved from the sending to the receiving end, with reflection at the latter, Voltmeter *A*, reading the initial wave, will show a reduced reading with increased length, while Voltmeter *B* will gradually increase its reading. Voltmeter *C* will vary in amplitude showing maximum and minimum points, i.e., the presence of standing waves due to the varying phase between the two traveling waves.

If the line is terminated in its surge or characteristic impedance, Voltmeter *B* will read zero at all points along the line, showing the absence of a reflected wave. Voltmeter *C* will vary in the same manner as Voltmeter *A* since they now read the same wave and will show the absence of standing waves when there is no reflection on the line.

In studying physical phenomena, apparatus which shows instantaneous relations and which can be arrested in its operation from time to time, or can be operated as slowly as desired, is of immense help in making the relations vivid to the student. Furthermore, analysis into components is always a potent method of understanding complex phenomena, and the author has found these models extremely useful in this respect.

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ELECTRICALLY CONDUCTIVE ANTIMONY MIRRORS ON GLASS

By Standish Miller

A non magnetic electrically conductive surface was needed on certain portions of the inner glass surface of a vacuum tube. It was necessary that the surrounding glass surfaces be electrically insulating. Silvered mirrors, sputtered mirrors, and metal shields have been used. Each has its disadvantages. A mirror of antimony made by the thermal decomposition of stibine was found to be satisfactory.

Antimony mirrors have been known since the discovery of stibine by Thompson in 1837.[1] He used their formation as a confirmatory test for the gas. These mirrors were also prepared by heating glass bulbs containing pure stibine by A. Stock and his co-workers[2] in their

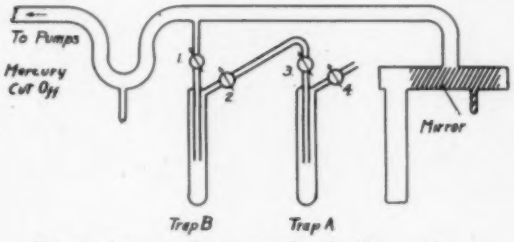

Fig. 1. *Apparatus for construction of antimony mirrors.*

investigations of the decomposition of stibine. Except as a qualitative test for antimony in the absence of arsenic with the Marsh apparatus, these mirrors have found few uses.

Stibine was prepared by the method of A. Stock and Doht[3] from a sintered mixture of 1 part of powered antimony with two parts of powdered magnesium. Ten grams of the alloy were slowly introduced in 300 cc of 12% hydrochloric acid. The resulting gases were bubbled thru water, dried with calcium chloride, and the stibine condensed with liquid air.

The trap *A* (Fig. 1) containing the condensed stibine was connected to the vacuum line as shown. With valve 4 closed and valves 1, 2, and 3 open, the whole apparatus was evacuated keeping *A* immersed in liquid

[1] Phil. Mag., (3) *10*, p. 353; 1837.

[2] Stock and Guttmann, Ber., *37*, p. 901; 1904, Stock, Gemolke, and Heynemann, Ber., *40*, p. 532; 1906 and Stock and Echeandia, Ber., *41*, p. 1309; 1907.

[3] Stock and Doht, Ber., *35*, p. 2270; 1901.

air. Valve 1 was closed, liquid air moved from trap *A* to trap *B*. Meanwhile, trap *A* was immersed in a salt and ice freezing mixture. After waiting 3 minutes for the stibine to distill, valve 2 was closed, valve 1 was opened, and *B* again evacuated. The mercury cut off was raised, the liquid air removed from *B* and stibine admitted to the main system until its pressure there was about 3 cm. The parts of the tube to be mirrored were cautiously heated with a flame. A smooth mirror forms wherever the tube is heated. These mirrors are stable in air and adhere well to the glass. They may be baked out under high vacuum at 300°C without sublimation. A simple mirror showed only a trace of sublimation in a vacuum after 12 hours at 340 to 355°. If the apparatus is of Pyrex, the antimony may be sublimed leaving a clean surface by heating until the glass begins to color the flame.

SUMMARY

Satisfactory electrically conducting mirrors of antimony on glass high vacuum apparatus have been prepared by the thermal decomposition of pure stibine. They do not sublime at 300° C. in a vacuum, but may be removed by sublimation at a temperature below the softening point of Pyrex.

The author wishes to thank Dr. George Glockler whose help and cooperation made this work possible.

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Colour and Colour Theories. By Christine Ladd-Franklin, Ph.D. Pp. xv+287. Harcourt, Brace, and Company New York, 1929. $3.50.

During a long a long and active career, Dr. Ladd-Franklin has had occasion to deal with specific aspects of color theory in the most pointed fashion possible. If her writings have had a controversial rather than a judicial tone, we may perhaps blame the restricted viewpoint of her contemporaries who simply would not see the logic of a perfectly logical position unless the points were hammered home with sledge-hammer strokes. At any rate, Dr. Ladd-Franklin's collected papers form a volume, which, by its very vigor, constitutes a contribution to the literature of color really unique. Colour and Colour Theories is no more like any other treatment of color vision in English, than a novel by Joseph Conrad is like a list for the year of the arrivals of sailing vessels. One may find a number of sources for a more or less orderly and adequate tabulation of the complicated facts of color vision. However, by their very nature, the description of these facts cannot be separated entirely from the particular color theory held by the writer of the description and since in any adequate summary, the work of various schools must be presented side by side for comparison, a confusion results with which readers of physiological optics are but too familiar. Although one *must* fight his way through one or another of these mazes to find out what is known and what is unknown about color vision, it is to Dr. Ladd-Franklin to whom one may profitably turn in order to find how these facts may be interpreted.

The volume will be particularly useful to have on one's desk provided the reader is one who, as many of us do, amuses himself with private suspicions and speculations concerning the nature of the visual process. If you are in the habit of remarking to yourself, "What's the matter with that idea, I wonder," you will probably find out by reference to Colour and Colour Theories. There is a good chance, indeed, of finding out the fallacy by reading one choice chapter, "An Ill Considered Colour Theory." Dr. Ladd-Franklin here exposes with such éclat the weaknesses of a rival theorist's scheme that (we are told in a footnote) the editor of the periodical later apologized for wasting ink on so fallacious an article.

Probably all theoretical treatments of color vision stress the phenomena which are most easily explained by the author's point of view, and to be sure, the reader will find in Colour and Colour Theories chiefly an exposition of the strengths of the Ladd-Franklin theory and the weaknesses of other theories. Dr. Ladd-Franklin succeeds, however, in explaining two important bodies of facts, one or the other of which is customarily ignored by color theorists, that is, she explains the *subjective side of color* in a way which permits us to understand the laws of *mixture of color stimuli*. This success is probably the basis for the increasingly wide acceptance which the Ladd-Franklin genetic theory of color vision is now enjoying.

The reader must not expect to find here a system so perfect that the results of all imaginable visual experiments may be accurately predicted, for the Ladd-Franklin theory is not such a system. The theory has, indeed, been criticized because it does not furnish ready-made predictions and hence does not stimulate research. It is true, that if we search the Ladd-Franklin theory for the specific function to represent quantitatively a given sort of visual response, we shall often discover the function undefined, but this shortcoming corresponds closely to the incompleteness of our knowledge and understanding of vision. It has been remarked of the Ladd-Franklin theory by Troland "that its basic outlines are probably essential to any satisfactory elucidation of the visual process." It is in this sense that the theory should be accepted and in which it is most valuable.

Some of the difficulty which has been encountered by Dr. Ladd-Franklin in achieving acceptance of her theory has doubtless been due to the reluctance of the physicist, on the one hand, and the psychologist, on the other, to admit that a mere logician, even so distinguished a logician as Dr. Ladd-Franklin, could possibly instruct them even slightly about their own fields of research. I confess that I, as a physicist, have been sometimes annoyed at having been reminded in no uncertain terms, not once, but many times, that I, a probable adherent of the Young-Helmholtz theory apparently had never seen yellow and must be psychically blind to it, (which is just a polite way of intimating that I was too stubborn to see it). It is likely, too, I suppose, that such psychologists as have thought the Hering theory of color vision tenable are annoyed when they are plainly told that their views indicate an inability to distinguish between the facts of color-mixture and a purely speculative hypothesis based on those facts. Nevertheless, it must admitted that both the physicist and psychologist, though they may not have entirely deserved all the harsh words showered upon them by this merciless and indomitable logician, have held views whose consistence was questionable and now stand in a position to benefit from the fruits of the labors of a logician whose grasp of the phenomena of color vision is truly remarkable.

Colour and Colour Theories opens quite aptly with the author's article appearing in the Dictionary of Philosophy and Psychology under "Vision." Then follow the important papers by which Dr. Ladd-Franklin introduced and defended her now well-known theory and those which deal with her discoveries in color vision. Although some of the papers originally appeared as early as 1892, the changes (which take the form of footnotes) required to take account of more recent discoveries are surprisingly few. The argument meanwhile is just as pointed and applicable to students of color vision now as ever; it is distinctly worth the consideration even of those who hold well-supported, partically conflicting views. The volume

is rounded off with a selected group of articles by other authors relevant to the Ladd-Franklin theory of color vision. A number of diagrams and illustrations throughout the volume (nine of them reproduced in color) serve as mnemonic aids to comprehension of the discussion.

D. B. JUDD

Lehrbuch der Optik. By Karl Försterling, Professor in the University of Cologne. 605 pages. Published by S. Hirzel, Leipzig, 1928. Sewed, 38 marks; bound, 40 marks.

Dr. Försterling is to be congratulated on the production of a very useful and thoroughly modern text book of optics. In a general way, the choice of subject matter is very commendable. As the author states in the preface, he has attempted not to produce an exhaustive work of reference, but rather a text book which will give the student a comprehensive view of the whole subject, because extensive accounts of the various branches of optics have recently appeared in the large German handbooks. In spite of this remark, it must be emphasized that a great deal of material has been introduced which will interest the specialist in optics. The author states that since no attempt has been made to furnish a complete account of the topics discussed, he has included only a few references. This is unfortunate, for the usefulness of the book could have been much enhanced by the inclusion of more references, without appreciable increase of bulk.

The book is divided into four sections. The first deals with general properties of light, such as velocity, energy, interference and polarization. The treatment here is quite conventional. Emphasis is placed on the physical ideas involved, rather than on mathematical proofs and details of apparatus. The entire section occupies only 47 pages.

The second section is the most extensive, consisting of 275 pages, and is devoted to the development of the Maxwell theory and the electron theory. Chapter 1 of this section deals with the elementary concepts of electrodynamics and the development of Maxwell's equations for a charge distribution in free space. Chapter 2 is devoted to the fundamental equations of the Lorentz theory, general boundary conditions, and the propagation of electric waves in free space and in conductors. The two last mentioned sections are quite brief and elementary. The next two chapters deal with dispersion and with reflection and refraction. It would be desirable, in the chapter on reflection and refraction, to give some account of Ewald's treatment of the subject.

Chapter 5 contains an extensive treatment of optical phenomena in crystals. This is more satisfactory than the treatment in any other text book with which the reviewer is familiar. There has been a tendency in previous books on optics to neglect the phenomena with which the petrographer is closely concerned, and it is refreshing to find in the present

volume a clear discussion of the phenomena observed when light passes through a crystal plate. Absorbing crystals are not neglected. The chapter closes with brief sections on dispersion in crystals and on the grating theory of crystals.

Chapter 6 deals with naturally active bodies and includes discussions of the dispersion of rotatory power and the grating theory of rotatory power. The next chapter deals with magneto optics and is confined entirely to the classical theory of such phenomena. The quantum theory of the Zeeman effect is reserved for the third section of the book.

Up to the present point, the discussion is based on infinitely extended waves. In chapters 8 and 9 the phenomena associated with limited wave fronts are thoroughly discussed. The first of these two chapters begins with a discussion of the Hertz vector. In other text books, the use of the Hertz vector in solving Maxwell's equations is scarcely touched upon. Prof. Försterling explains very clearly the advantages to be gained by using this vector.

He passes then to a discussion of Huygen's principle as modified by Kirchhoff, and deals with a number of diffraction problems. Diffraction at a half plane is treated first by Young's method and then by more recent and more rigorous methods. Sections on diffraction at a very small sphere and in colloidal solutions are included.

The next chapter is quite brief and is devoted to the equation of propagation in inhomogeneous media. Considerable attention is given to the special case of stratified media, but applications in meteorology are not mentioned. Chapter 11 is devoted to the optics of moving media. Doppler's principle is treated with the aid of the retarded potentials, an interesting variation on the usual derivation. The Lienard-Wiechert potentials of a moving point charge are next developed, and the corresponding expressions for the field strengths are obtained, including terms in the acceleration. The field equations for propagation in a uniformly moving body are now derived and are applied to the experiment of Fizeau and the Michelson-Morley experiment. The treatment of the relativity principle is very brief. The author explains in the preface that he has not attempted to deal in an adequate way with the relativity theory. He prefers to confine himself to the more physical treatment of such questions, which was developed by Lorentz, because it furnishes an easily understandable basis for the Lorentz transformation.

We now come to the third section of the book, 158 pages in length, which is composed of chapters on the theory of series spectra, heat radiation and experimental facts in regard to radiation by atoms. The first of these is almost entirely mathematical. The Bohr-Rutherford model of hydrogen is discussed and the author then launches on a derivation of the general equations of mechanics, including the Lagrangian equations for cases in

which the most general type of electromagnetic field is present. These equations are then applied in detail to the hydrogen atom, after which the Schrödinger theory is explained in the space of about twenty pages. Finally, the chapter ends with a very brief discussion of experimental facts in regard to line and band spectra. The reviewer believes that this experimental material might well have been placed in advance of the mathematical discussion. The necessity for the mathematical treatment can hardly be appreciated by the student until he has acquired some knowledge of the facts to be explained. The second chapter, on temperature radiation, is thoroughgoing and very clear. Auxiliary theorems of thermodynamics are developed in detail, so that the reader need not turn to any other book in order to understand this subject in its entirety. The chapter ends with Einstein's derivation of Planck's law, but this section includes no mention of his hypothesis of unidirectional light quanta. Chapter 3 treats briefly the following topics: resonance radiation, collisions of the second kind, fluorescence and phosphorescence, excitation by electronic collision, photo-electric effect, Compton effect, experiments on the duration of emission, breadth of spectral lines, and special interference experiments, such as those with very weak sources. The probability interpretation of the electric and magnetic intensities, furnishing a connection between the wave and photon theories, is also discussed. This interpretation might well be mentioned earlier in the discussion, and would throw a flood of light on the phenomena considered in this chapter.

The fourth section of the book, 168 pages in length, deals with the theory of optical instruments. In this brief space it is obviously impossible to develop formulas which would be of aid in calculating optical systems. Attention is therefore concentrated on giving the reader some idea of the defects of the image and the conditions under which they occur. This section also contains a treatment of the more important types of spectroscopic apparatus.

There are appendices on Voigt's theory of the anomalous Zeeman effect, on Maxwell's equations in curvilinear coordinates, and on the canonical equations of dynamics, as well as a collection of formulas dealing mostly with vector calculations.

In conclusion, this book fills a real need for an authoritative treatment of optical theory which attempts to give complete derivations as clearly as possible and to furnish a reasonable amount of experimental material designed to show the range of validity of the theory. It furnishes a desirable complement to a treatment like that in Wood's "Physical Optics," and should prove very useful to a wide circle of readers.

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